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Dosimetric verification of the dose distribution in pulsed dose rate brachytherapy

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Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

Summary

Background Pulsed dose rate (PDR) brachytherapy is clinically used as an irradiation technique. It combines the physical advantages of high-dose-rate (HDR) technology (isodose optimization, planning flexibility and radiation safety) with the radiobiological advantages of low-dose-rate (LDR) brachytherapy [1,2]. The single radioactive stepping source moves through all the implanted catheters during each pulse. The source is enclosed in a capsule 2.5mm long with a diameter of 1.1mm [3]. The resulting isodoses can be optimized by modulating the dwell time of the source as a function of its trajectory within the implanted volume.

Aim The aim of this study was the dosimetric verification (*in-phantom*) of doses calculated with the Plato treatment planning system (TPS) by using GafChromic films and thermoluminescent detectors (TL) in PDR brachytherapy.

Materials/Methods Absorbed doses at chosen points were measured with TL detectors, while dose distributions were measured with GafChromic films. Dose measurements were made at 14 reference points in a specially designed, tissue equivalent phantom. The prescribed doses were compared with the measured doses. A fusion of two dose distributions was made. The image read from the dosimetric film after its digitalization was fused with the one received from TPS. Qualitative analysis of this fusion was performed.

Results Wilcoxon test and sign test (dependent samples) were used to compare the doses calculated with those measured with TL detectors. The statistical comparison of doses calculated and measured revealed differences in the range of – 14.7% to 12.6%. These results fitted well with the results of qualitative analysis made using images' fusion made for calculated and measured dose distributions.

Conclusions Both quantitative and qualitative analysis proved the correctness of the calculation algorithms used by the Plato planning system in a phantom study for PDR brachytherapy.

Key words **PDR brachytherapy • dose verification • dose measurements • thermoluminescent dosimetry • GafChromic film**

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Background

Pulsed dose rate (PDR) brachytherapy is clinically used as an irradiation technique. It combines the physical advantages of high-dose-rate (HDR) technology (isodose optimization, planning flexibility and radiation safety) with the radiobiological advantages of low-dose-rate (LDR) brachytherapy [1,2]. The single radioactive stepping source moves through all the implanted catheters during each pulse. The source is enclosed in a capsule 2.5mm long with a diameter of 1.1mm [3]. The resulting isodoses can be optimized by modulating the dwell time of the source as a function of its trajectory within the implanted volume.

In our radiotherapy department about 15% of all radiotherapy patients are treated with brachytherapy. Pulsed dose rate (PDR) brachytherapy is used to treat many types of cancer. A typical treatment in which PDR brachytherapy may be used is, for example, the treatment of cancer of the cervix. Radioactive sources are placed in or near the tumour itself, giving a high radiation dose to the tumour while reducing the radiation exposure in the surrounding healthy tissues. Various applicators are in use to hold the sources in an appropriate configuration. A cervix applicator consists of a central tube (tandem) and lateral capsules (ovoids). In remote afterloading devices Ir^{192} is used as a radioactive source [3–5].

Aim

The aim of this paper was the dosimetric verification (*in-phantom*) of calculated dose distribution by the Plato treatment planning system in PDR brachytherapy using GafChromic films and thermoluminescent detectors (TLD).

Materials and Methods

Doses were measured with thermoluminescent (TL) detectors [6–8]. TLD-100 detectors ($3.0\times3.0\times0.9mm^3$) made of LiF and a Harshaw 3500 TLD Reader were used.

Pre-irradiation annealing was carried out at 400°C for 1h, then at 100°C for 4h followed by cooling to room temperature. The detectors were read out at 260°C. TL dosimeters were calibrated in a Co-60 beam [7]. Calibration was carried out in a PMMA phantom with 5mm build-up in a homogeneous field $20\times20cm^2$. Stability of the detectors was within 3%.

Dose distributions were measured with GafChromic MD-55 films [8,9]. The film was placed between the two pieces of phantom, parallel to the catheter axis. Images obtained on the basis of the dosimetric films were digitalized in 24 bit colour scale. Then they were analyzed using the Origin v.7 application. The films used in this study were not calibrated. Therefore dose distributions obtained using radiochromic films were digitalized and used only for visual comparison with the dose distributions, which were calculated using Plato v.14.1.3 by the Nucletron treatment planning system.

The measurements were performed in the tissue equivalent phantom designed by the authors. The phantom consisted of two parts, which were connected. A hole was drilled in the middle of the boundary between the parts in which the source was input. Both parts had the shape of rectangular prisms ($30\times22\times6cm^3$) and were made of alloy of a wax and paraffin mixture. The catheter was inserted into the hole. A total of 14 TL-detectors were placed in the selected dosimetric points and GafChromic film was placed between the two pieces of phantom. The phantom used in the study is shown in Figure 1.

The brachytherapy treatment plan was calculated in the Plato planning system. 14 reference points were determined. The Integrated Brachytherapy Unit (IBU) was used to verify the positions of the applicator and detectors [10]. The treatment plan was made on the basis of received images, shown in Figure 2. The distance between consecutive dwell points was 2.5mm; however, distance between reference points was 5.0mm. The dose

Figure 1. The tissue equivalent phantom used for dosimetric verification of the dose distribution in PDR brachytherapy.

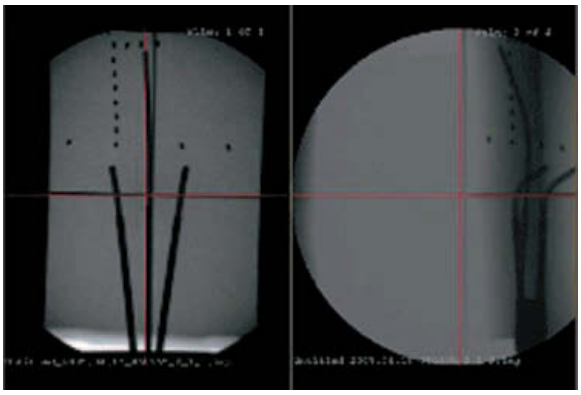

Figure 2. Verification of images from the Integrated Brachytherapy Unit (IBU).

Table 1. Doses from PDR brachytherapy treatment measured at 14 reference points.

Reference points	Measured doses [Gy]			
	D_m1	D_m2	D_m3	D_m4
P1	8.46	8.50	8.54	9.03
P2	34.12	32.49	32.90	30.33
P3	32.80	31.45	30.03	29.22
P4	–	9.29	9.00	8.61
P5	35.97	34.65	29.44	31.18
P6	39.26	35.11	34.07	33.23
P7	–	38.99	34.55	31.31
P8	33.29	31.52	29.41	26.55
P9	29.10	28.54	26.94	26.32
P10	21.65	20.67	18.03	17.94
P11	15.56	14.72	13.31	13.29
P12	24.03	23.29	19.48	19.23
P13	30.27	28.78	24.51	22.86
P14	25.93	25.54	21.24	21.10

was given with a microSelectron PDR afterloading unit (Nucletron).

The prescribed doses were compared with the measured doses. Wilcoxon test and sign test (dependent samples, confidence level 95%) were used to compare the prescribed doses (calculated by TPS) with doses measured by thermoluminescent detectors [7,11–13].

The fusion of images with dose distributions was made. The image read from the dosimetric film after its digitalization was fused with the one received from TPS. Qualitative analysis of this fusion was performed.

Results

Four series of measurements were made. Results of doses measured using thermoluminescent detectors ($D_m1,\ldots, D_m4$) are shown in Table 1. The symbol "–" means that the result of the measurement was rejected because of major error. The rejection was made when the result was more than the standard deviation multiplied by 3 (D_m>3SD).

Table 2 shows mean measured doses ($\bar{D}_m$) and calculated doses (D_c) by TPS for each reference point. The TPS calculation error (ΔD_c) is about 5%. However/Additionally, for each of the measured doses the value of the standard deviation (SD) was calculated. Also, the difference (R) between the calculated dose (D_c) and mean measured dose ($\bar{D}_m$) was calculated using formula (1):

$$R = \left(\frac{\bar{D}_m - D_c}{D_c} \right) \cdot 100\% \qquad (1)$$

The results of the calculated and measured doses, shown in Table 2, were analyzed using statistical methods. The final results of the statistical verification of calculated (D_c) and measured ($\bar{D}_m$) doses are shown in Table 3. Wilcoxon test and sign test were used. Calculated p-value was analyzed with confidence level α=0.05.

On the basis of tests carried out, no statistically significant differences between calculated and measured doses were affirmed.

The image obtained from the exposure of radiochromic film to irradiation is shown in Figure 3.

Table 2. Prescribed doses (D_c) and mean measured doses ($\overline{D}_m$) at 14 reference points and calculated statistical values – standard deviation (SD), calculation error (ΔD_c), difference (R).

Reference points	$\overline{D}_m$ [Gy]	SD [Gy]	D_c [Gy]	ΔD_c [Gy]	R [%]
P1	8.63	0.26	10.08	0.50	–14.4
P2	32.46	1.58	29.76	1.49	9.1
P3	30.87	1.58	30.24	1.51	2.1
P4	8.97	0.34	10.51	0.53	–14.7
P5	32.81	3.02	31.53	1.58	4.1
P6	35.42	2.68	31.46	1.57	12.6
P7	34.95	3.85	32.22	1.61	8.5
P8	30.19	2.90	28.66	1.43	5.3
P9	27.72	1.31	25.86	1.29	7.2
P10	19.57	1.88	19.97	1.00	–2.0
P11	14.22	1.12	15.43	0.77	–7.8
P12	21.51	2.50	20.38	1.02	5.5
P13	26.61	3.49	25.64	1.28	3.8
P14	23.45	2.64	23.07	1.15	1.7

Table 3. Calculated p-value for determined reference points for Wilcoxon test (column 2) and sign test (column 3).

Reference points	D_c vs. D_m (p-value)	
	Wilcoxon	Sign Test
P1	0.125	0.125
P2	0.125	0.125
P3	0.625	1.000
P4	0.250	0.250
P5	0.625	1.000
P6	0.125	0.125
P7	0.500	1.000
P8	0.375	0.625
P9	0.125	0.125
P10	0.625	1.000
P11	0.250	0.625
P12	0.625	1.000
P13	0.625	1.000
P14	0.625	1.000

The red circles mark the positions of two reference points (P1 and P2).

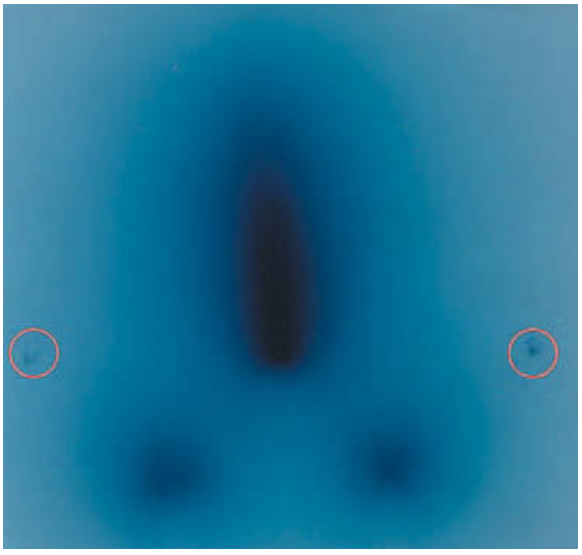

Figure 3. Image obtained from the exposure GafChromic MD-55 film to radiation.

The dose distribution obtained after carrying out the analysis of MD-55 dosimetric films using the Origin application is shown in Figure 4. The red circles show the positions of two reference points (P1 and P2).

A fusion of two images was made: the image from the dosimetric films after digitalization and the dose distributions from the treatment planning

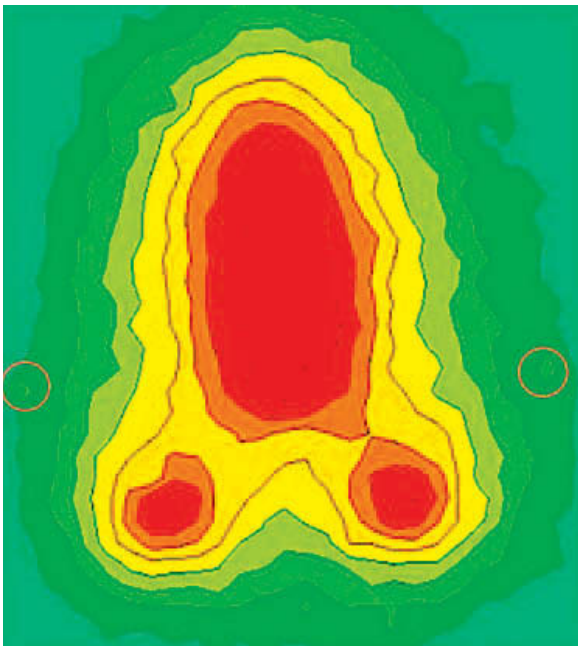

Figure 4. Dose distribution obtained after the analysis of irradiated MD-55 dosimetric films.

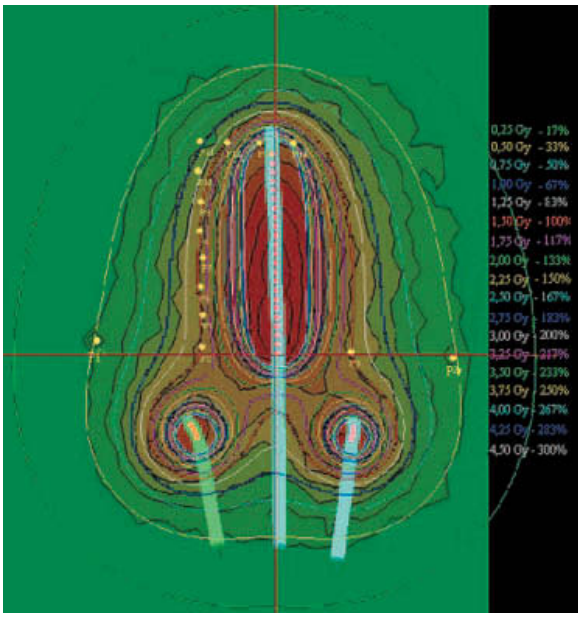

Figure 5. The fusion of two distributions from dosimetric film digitalization and from treatment planning system.

system (Figure 5). The overlapping areas were revealed. As a result it was affirmed that the calculation algorithms used by the Plato planning system gives reliable dose distributions [7,8].

Discussion

The author's phantom made especially for this work was very useful. It simulated the patient, but could also be used for measurements using TLDs and GafChromic films. Commercially available phantom dose not support both kind of measurements at the same time. The developed phantom made it possible to position the TL detectors in the places described by the authors. The phantom can be used for additional and other work in the future.

Using the phantom, 4 measurements were made at 14 reference points using thermoluminescent detectors. For each point the average value, the standard deviation and also the difference between the calculated and measured doses were calculated. On the basis of the measurement results, it was confirmed that the calculation algorithm used by the Plato treatment planning system works correctly [7,8,14,15]. It was found that there are no statistically significant differences between the calculated and measured doses. Some of the measurement points have occurred to the differences between doses measured and calculated. The high dose gradient area and the probability of inaccurate positioning of TLD in the phantom could have an influence on the error.

For the qualitative analysis of the dose distributions obtained from the treatment planning system and from the irradiation, radiochromic films were used [7,8,16]. GafChromic MD-55 film has several advantages – high spatial resolution, relatively low spectral sensitivity, near tissue equivalence – and it requires no special development procedure. Furthermore, it has low sensitivity to room light, which makes handling easy. The new films consist of double-layer radiochromic sensors dispersion coated on both sides of a polyester base. The colourless and transparent film responds to ultraviolet light and to ionizing radiation by turning blue. The overlapping areas have shown good agreement between both dose distributions. This also confirms that the calculation algorithm used by Plato leads to reliable dose distributions for PDR brachytherapy.

Conclusions

1. It was proved that the tissue equivalent phantom designed by the authors was very useful for measurements using TLDs and GafChromic films in PDR brachytherapy.

2. On the basis of the dosimetric measurement results, it was confirmed that the calculation algorithm used by the Plato treatment planning system works correctly. It was found that there

are no statistical significant differences between the calculated and measured doses.

3. On the basis of the qualitative analysis of the calculated and measured dose distributions, it was affirmed that the calculation algorithms used by the Plato planning system gives reliable dose distributions.

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